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UNITED STATES BUREAU OF MINES
Scott Turner, Director

INFORMATION CIRCULAR

EXPLOSIONS IN COLORADO COAL MINES, 1883 TO 1932

BY

B. M. Kintz and E. H. Denny

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INTRODUCTION

In safety work a study of past accidents is of value in determining means of reducing future accidents of the same character. This is particularly true with reference to coal-mine explosions. Data from publications of the United States Bureau of Mines and from published reports of the State inspector of coal mines of Colorado are presented in this circular in the belief that they will be of value to operators by indicating methods of preventing future coal-mine explosions. The tables included are complete only with regard to major disasters. The Bureau of Mines considers as a major disaster one in which five or more men are killed. However, this circular also includes a considerable number of minor disasters. Various explosions in the coal mines of Colorado from 1883 to 1932, inclusive, are listed with information available as to their probable cause, number of men killed, and measures which, if they had been in use at that time, might have prevented them.

John McNeil, first Colorado State coal-mine inspector, on page 43 of his first report for the period ended July 31, 1884, made the following recommendations for the prevention of explosions in the coal industry:

> True causes could be traced either to insufficient ventilation, carelessness and lack of rigid discipline in carrying on energetic ventilation and other precautions needed to be enforced in a mine giving off explosive gases. *** When any quantity of fine coal dust is observed in an entry, air course, or room it should be made damp and be removed from the mine, and thus keep every place as free from dust as possible. *** A system of bratticing close up to the face of each and every place in the mine from crosscut last made (whether gas should just then show its presence or not) which should not be more than 50 or 75 feet according to the nature of the mine.

He recommended noninflammable stoppings, "air bridges," and many other gas-ignition prevention measures that are used today, with the exception of permissible equipment, electric lamps, and rock-dusting. He also suggested the use of lime cartridges in place of black blasting powder.

Explosions still occur despite these early recommendations and the adoption by many operators of better ventilation and blasting methods, rock-dusting, and more modern coal-handling appliances. The importance of adequate ventilation, rock-dusting, the use of permissible explosives in a permissible manner, the use of permissible mining equipment in gassy mines, and thorough testing for the presence of inflammable gas is generally understood by the industry. Few mines, however, have completely carried out all means of explosion prevention, and as long as one or more of these factors is neglected explosions will still occur.

Table 1 gives available data regarding the cause, number killed and injured, and possible means of prevention at the time of 119 explosions that occurred in Colorado from 1883 to 1932, inclusive.

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[1] The Bureau of Mines will welcome the reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6753."

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TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
1	11/29/1883	Gunnison	Slope	47,524	75	-	Local	Feeder at face. Door left open short-circuited air	Open light	Some positive means of insuring doors are closed. Use of air bridge	Gas	1	3	71
2	1/2/1884	Huerfano	do.	17,976	50	-	do.	Poor ventilation of working place. Brushing out gas	Brushed gas out of room with coat onto open light on entry	Brattice cloth. Inspection. Forbid brushing out gas	do.	0	1	[2]49
3	1/24/1884	Gunnison	do.	47,524	75	-	Entire mine	Broken-down brattice at face of room	Open light	Not moving gas with men in mine. Sprinkling	Gas and dust	59	1	10
4	1/12/1885	Fremont	do.	[1]129,099	-	-	Local	Gas in abandoned area	Men with open lights disregarded "danger board" and entered gassy area	Inspector recommended discipline and that fire boss eradicate gas by proper ventilation	Gas	1	4	-
5	1/14/1888	do.	Shaft	-	335	-	do.	Fired shot, liberated gas	Open light	Better ventilation	do.	1	4	-
6	1/19/1888	do.	do.	-	335	-	do.	-	do.	Better ventilation	do.	0	1	-
7	2/9/1888	Park	Slope	23,421	80	-	do.	-	do.	Better ventilation	do.	0	1	-
8	4/25/1888	Las Animas	Drift	302,000	236	-	do.	-	do.	Better ventilation	do.	0	1	-
9	7/10/1888	Fremont	Slope	[1]154,520	158	-	do.	-	do.	Better ventilation	do.	0	1	-
10	11/5/1888	Las Animas	Drift	181,270	204	2	Entire mine	Dead-end entry filled with gas. No line brattice	Open light. Explosion set off 6 kegs of black blasting powder and a box of 30% dynamite	Inspector recommended sprinkling of all workings. Only small amount of explosives to be kept in mine	Gas and dust	2	0	0
11	12/3/1888	Garfield	do.	Being developed	Unknown	0	do.	Dust on floor, ribs, and roof raised by shots	Blown-out shot	Inspector recommends sprinkling with water under pressure	Dust	[4]3	[4]8	0

[1] Includes production of 2 mines.

[2] Estimated.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
12	12/10/1888	Fremont	Slope	3/154,520	158	11	Entire mine	Gas leaked from sealed-off area while fighting fire	Open lights	Use of flame safety lamps	Gas	2	9	0
13	9/3/1889	Garfield	Drift	49,147	150	-	Local	-	do.	Better ventilation	do.	0	1	Unknown
14	1/29/1890	Park	Slope	35,093	123	-	do.	Lack of line brattice caused gas to accumulate in working place	Open lights. Miner brushed out gas with shirt onto other miners' open lights	Inspector recommended use of line brattices and no open lights in section	do.	1	3	do.
15	3/29/1890	do.	do.	35,093	123	-	do.	-	Open lights	Better ventilation	do.	0	2	do.
16	10/24/1891	Garfield	Drift	11,211	60	-	do.	-	do.	do.	Gas &Dust	2	0	do.
17	12/18/1891	Park	Slope	52,626	150	-	do.	-	do.	do.	Gas	0	1	do.
18	9/28/1892	Huerfano	do.	69,959	120	-	do.	-	do.	do.	do.	2	-	-
19	10/6/1892	Garfield	Drift	43,780	70	-	do.	Dust raised by shots	Blown out shot	Sprinkling	Dust	1	4	-
20	1/10/1893	Park	Slope	-	-	-	-	-	Blown out shot of black blasting powder	Better ventilation, sprinkling	Gas and dust	24	-	-
21	1/22/1893	Fremont	Shaft	5,856	40	-	Local	-	Open lights	Better ventilation	Gas	0	2	-
22	6/22/1893	do.	do.	5,856	40	-	do.	-	do.	do.	do.	0	1	-
23	11/13/1893	do.	Slope	6/117,659	5/425	-	do.	-	do.	do.	do.	0	1	-
24	11/30/1893	do.	Shaft	5,850	40	-	-	-	do.	do.	do.	0	2	-
25	4/20/1894	Garfield	do.	83,693	200	-	-	Dust raised by shots	Blown-out shot ignited dust	Sprinkling	Dust	-	6	-
26	4/9/1895	do.	do.	114,923	148	-	Local	-	Open lights	-	Gas	-	1	-
27	5/10/1895	Las Animas	Slope	233,422	354	-	do.	Door propped open, short-circuiting air	do.	Better ventilation and discipline	do.	4	0	-
28	12/9/1895	Park	do.	41,881	111	-	do.	-	do.	-	do.	0	1	-
29	12/28/1895	Las Animas	do.	233,422	354	-	do.	-	do.	-	do.	0	1	-
30	2/18/1896	Garfield	do.	14,533	-	49	Entire mine	Unable to detect small quantities of gas with flame safety lamp	Uncertain; probably shot black blasting powder in chute	State inspector said there was nothing that equipment on the market at that time could do. He wished for better explosives and gas tester	Gas and dust	49	-	-

3/ Includes production of 2 mines. 5/ Includes 2 mines.

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
31	2/29/1896	Park	Slope	33,887	106	-	Local	-	Open lights	-	Gas	0	1	-
32	3/23/1896	do.	do.	33,887	106	-	do.	-	do.	-	do.	0	1	-
33	4/16/1896	Las Animas	Drift	115,203	150	-	do.	-	do.	-	do.	0	1	-
34	3/24/1897	do.	Shaft	30,494	-	-	do.	-	do.	-	do.	0	1	-
35	6/9/1897	do.	Slope	156,936	176	-	do.	-	do.	-	do.	0	1	-
36	9/3/1897	Garfield	Drift	36,428	42	-	-	Dust raised by blasting	Uncertain; probably blown-out shot of black blasting powder	Shooting with only shot firers in the mine or using electric blasting	Dust	12	-	-
37	10/18/1897	Gunnison	Slope	233,906	311	-	Outside mine at tipple	Runaway trip down incline smashed through tipple causing dust cloud	Runaway trip upset stove on tipple	Automatic derailing	do.	0	2	-
38	1/8/1898	Las Animas	Shaft	10,770	50	-	Local	-	Open lights	-	Gas	0	1	-
39	6/30/1898	do.	Slope	171,535	176	-	do.	-	-	-	do.	0	1	-
40	4/21/1899	Huerfano	do.	113,853	150	-	-	Unknown	Unknown	Better ventilation	do.	0	1	-
41	4/21/1899	Garfield	Shaft	30,174	105	-	-	-	Open lights	do.	do.	0	2	-
42	4/27/1899	Las Animas	Drift	507,615	502	-	-	-	do.	do.	do.	0	1	-
43	11/12/1899	Garfield	Slope	34,603	40	-	-	-	do.	do.	do.	0	1	-
44	11/24/1899	Gunnison	Drift	15,508	60	-	-	-	do.	do.	do.	0	2	-
45	2/7/1900	Las Animas	do.	253,424	275	-	-	-	do.	do.	do.	0	2	-
46	2/18/1900	Huerfano	Slope	50,303	123	-	-	-	do.	do.	do.	0	1	-
47	3/31/1900	do.	do.	96,556	182	-	-	-	do.	do.	do.	0	1	-
48	4/14/1900	Garfield	do.	56,728	45	-	-	-	do.	do.	do.	0	1	-
49	4/23/1900	Gunnison	Shaft	73,430	90	-	-	-	do.	do.	do.	0	2	-
50	5/7/1900	Garfield	Slope	56,728	45	-	-	-	do.	do.	do.	0	2	-
51	5/21/1900	Las Animas	do.	255,179	300	-	-	-	do.	do.	do.	0	4	-
52	10/2/1900	Huerfano	do.	54,631	41	-	-	-	do.	do.	do.	0	1	-
53	10/20/1900	do.	do.	50,303	123	-	-	-	do.	do.	do.	0	1	-
54	1/8/1901	Garfield	Drift	Not listed	10	2	Entire mine	Improperly placed shots raised dust cloud. No gas	Blown-out shot at face of entry	Better placing of shots	Dust	2	0	0

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
55	1/27/1901	Pitkin	Slope	81,688	222	-	-	-	Open lights	Better ventilation	Gas	0	1	-
56	2/18/1901	Fremont	Shaft	86,576	70	-	-	-	do.	do.	do.	0	1	-
57	4/15/1901	Garfield	Slope	19,684	37	-	-	Improper ventilation See case 61	do.	Better ventilation; proper coursing of air	do.	0	1	-
58	4/17/1901	do.	do.	19,684	37	-	-	do.	do.	do.	do.	0	4	-
59	5/9/1901	Boulder	Shaft	8,633	10	-	-	-	do.	Better ventilation	do.	0	2	-
60	5/21/1901	Las Animas	Slope	322,825	441	-	-	-	do.	do.	do.	0	1	-
61	5/31/1901	Garfield	do.	19,684	37	5	Entire mine	Too small an air course; improper method of coursing air	do	Increase in size of air course. Proper inspection of mine before miners enter. Better ventilation	do.	6/2	7/7	0
62	9/16/1901	Gunnison	Drift	26,620	Not listed	-	-	-	do.	Better ventilation	do.	0	2	-
63	9/16/1901	Pitkin	Slope	214,643	137	3	Entire mine	Mine damp. Dust raised by blasting	Blown-out shot of black blasting powder	None recommended by State inspector	Dust	8/6	3	0
64	12/27/1901	Gunnison	Shaft	77,851	105	-	-	-	Open lights	Better ventilation	Gas	0	1	-
65	1/20/1902	Huerfano	Slope	137,401	153	-	Local	Cave at face of room nearly blocked crosscut	do.	Better ventilation Keeping crosscuts open	do.	3	2	More than 3
66	4/23/1902	Boulder	Shaft	5,270	10	-	do.	Door left open, short-circuiting air	do.	Double doors or air bridge (overcast)	do.	1	2	-
67	7/21/1902	Fremont	Slope	18,162	51	-	do.	-	do.	Better ventilation	do.	0	1	0
68	7/28/1902	Garfield	Rock tunnel	790	5	1	Entire mine	Dust raised by shots	Not certain. Probably blown-out shot	Sprinkling	Dust	1	0	0

6/ Miners killed outside of mine.

7/ Miners burned outside of mine.

8/ 3 miners outside of mine were killed.

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
69	8/2/1902	Las Animas	Shaft	Abandoned	5	5	Shaft	Old abandoned shaft known to be filled with gas	Not certain. Probably one of men working on pump rod in shaft struck a match to light pipe	More care in working around abandoned gassy mines	Gas	4	1	0
70	8/7/1902	do.	Drift	143,464	145	13	Entire mine	Mine nongassy but very dusty. Dust raised by explosives	Explosion of dynamite stored in mine	Sprinkling. Cleaning up of dust	Dust	13	0	0
71	9/2/1902	Huerfano	Slope	52,501	105	-	Local	-	Open lights	Better ventilation	Gas	0	2	0
72	7/11/1903	Garfield	Drift	48,632	34	1	Entire mine	Shots raised dust cloud. Mine very dusty although equipment and water for sprinkling were available	Blown-out shot. Dynamite	Discipline. Sprinkling	Dust	1	0	0
73	10/28/1904	Las Animas	do.	128,035	247	18	do.	Shots on solid. Miners not allowed to fire shots but did. Raised dust cloud	Blown-out shots	Better discipline. Shot firers were only ones allowed to fire shots. Miners disobeyed rules. Better location of holes	do.	19	0	0
74	2/19/1906	Huerfano	Slope	135,508	Not given	-	Local	Sudden outburst of gas	Open lights	Use only flame safety lamp in pillar workings	Gas	14	-	-
75	4/19/1906	Las Animas	Drift	241,152	-	-	do.	-	No details given	-	do.	1	-	-
76	4/22/1906	do.	do.	85,824	Not given	43	-	Room filled with gas after being examined and found clear	Open lights	Flame safety lamps. Better ventilation	Gas-dust	9/19	2	22

9/ Includes son visiting father.

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
77	7/16/1906	Las Animas	Slope	105,714	-	-	Local	-	-		Gas	1	-	-
78	1/23/1907	do.	Drift	426,325	Est. 200+	24	Entire mine	Unknown. State inspector said possible for door to have short-circuited air	Unknown. May have been open safety lamp	Cause too uncertain to make definite recommendations	Gas-dust	24	0	0
79	4/24/1907	Huerfano	Slope	125,004	-	-	-	-	-	-	Gas	1	-	-
80	12/20/1907	do.	do.	111,410	-	-	Local	Shot on solid raised dust cloud	Blown-out shot. Shot on solid	Better location of drill holes	Dust	1	-	-
81	3/15/1908	Boulder	Shaft	105,873	-	-	do.	-	Probably open lights	Better ventilation	Gas	1	-	-
82	4/14/1908	La Plata	Tunnel	6,281	-	-	do.	-	Open lights	do.	do.	1	-	-
83	9/1/1908	Boulder	Shaft	37,545	-		-	-	do.	-	do.	1	-	-
84	11/9/1908	Mesa	-	-	-	-	-	-	-	-	do.	1	-	-
85	5/4/1909	Las Animas	Slope	304,305	-	-	Local	-	-	-	do.	1	-	-
86	7/6/1909	do.	Shaft	46,338	-	9	Entire mine	Stopping of fan over July 4 and 5	Open lights	Better ventilation by continued operation of fan	do.	9	-	-
87	11/14/1909	do.	Slope	273,167	-	1	Local	Dust raised by shots	Blown-out shot	Shots fired by electricity	Dust	1	-	-
88	12/14/1909	do.	do.	143,368	82	2	Entire mine	do.	do	All shots fired by electricity from outside mine	do.	2	0	0
89	1/31/1910	do.	Drift	271,747	110	76	do.	Unknown	Uncertain	Sprinkling should be done more thoroughly	Gas-dust	75	0	1
90	10/8/1910	do.	do.	266,605	200	56	do.	Dust on timbers. Trip not sprinkled	Trolley trip split. Electric arc	Keep timbers free of dust and sprinkle sides and roof as well as road bed	Dust	56	0	-
91	11/8/1910	do.	Slope and 4 drifts	556,791	157	157	Local	Some persons claim explosion of CO. No gas found in mine	Haulage door caught on fire. Probably open lights	Use of overcast to eliminate doors on haulage roads	Gas-dust	[10]79	-	78

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[10] Includes outsiders.

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
92	2/9/1911	Las Animas	Slope	295,925	263	15	Local	Coal dust in gob. Excess of explosives in gob. Dust raised by shots	Blown-out shot	Proper storage of explosives; proper explosives	Dust	10/17	-	2
93	5/4/1911	do.	do.	286,359	140	-	do.	Gas in abandoned workings	Open lights	Use of flame safety lamp	Gas	1	4	-
94	6/18/1912	do.	do.	231,468	198	43	Entire B seam	Deranged air current due to canvas "down" or door open	Defective safety lamp	Inspection and safe use of flame safety lamps	do.	12	1	30
95	8/29/1912	do.	do.	-	205	190	Local	Pocket of gas at roof Using carbide light and flame safety lamp at same time	Open lights	Better ventilation. Flame safety lamps	do.	2	0	4
96	10/1/1912	Garfield	Drift	32,514	71	-	-	Poor ventilation. No sprinkling. Dust raised by shots	Blown-out shot or open lights	Better ventilation and sprinkling	Gas-dust	2	0	-
97	11/8/1912	Boulder	Shaft	81,599	94	-	-	Gases distilled by fire	Fire ignited gases	-	Gas	1	4	-
98	12/16/1913	Garfield	Drift	76,096	48	37	Entire mine	Cloud of dust raised by fall of roof coal or rush of coal	Black blasting powder or open lights	Sprinkling	Dust	37	-	-
99	1/17/1914	Huerfano	Slope	51,555	91	-	Local	Blown-out shot and coal dust	Blown-out shot, on solid	Inspection and firing of shots by shot firers	do.	2	-	-
100	6/28/1914	Las Animas	Shaft	31,418	46	1	do.	Door left open	Relighting opened flame safety lamp	Proper ventilation. Proper handling of flame safety lamp	Gas	1	-	-
101	5/2/1915	Huerfano	do.	39,585	50	-	-	Air short-circuited through crosscut opened to remove rock for overcast	Open lights	Proper ventilating methods	do.	2	-	-

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
102	4/27/1917	Las Animas	Slope	74,221	152	122	Entire mine	Probably due to short circuiting of air. Door left open or curtain "down"	Safety inspector trying to relight flame lamp with a match	Stricter supervision and magnetically locked flame safety lamps properly maintained and used	Gas-dust	121	0	31
103	11/4/1918	Garfield	Shaft	36,638	43	-	-	Gas accumulated in rooms to pitch	Mine fire. Fire caused by spontaneous combustion	Proper ventilation	Gas	3	4	Unknown
104	3/31/1919	Las Animas	Slope	45,686	54	13	-	Fan stopped 2 hours on account of burned-out bearing	Short-circuit of electric feed wires	Cutting all power off mine when fan stops. Better installation of feed wires	do.	13	-	-
105	8/18/1919	Huerfano	do.	146,354	169	-	Entire mine	-	Defective flame safety lamp, blown-out shot, or matches	Properly maintained flame safety lamps. Use of permissible explosives. Obeying State laws	do.	18	-	-
106	2/12/1921	Routt	Drift	271,594	310	-	do.	Dust raised by shots	Blown-out shot of black blasting powder	Sprinkling at face. Use of permissible explosives	Dust	5	-	-
107	3/24/1922	Las Animas	Slope	262,094	175	17	do.	Locking door open short-circuited air	Nips of electric cutting machine	Overcast	Gas-dust	17	0	0
108	5/5/1923	do.	do.	32,831	54	10	do.	Fan stopped	Open lights	Permissible lamps; auxiliary power on fan	do.	10	0	0
109	10/7/1923	Mesa	Drift	18,056	34	7	do.	Poor ventilation. Fan operated intermittently. Not run at night	do.	Permissible lamps; continuous operation of fan	do.	6	-	1
110	8/5/1924	Huerfano	Slope	84,639	70	5	Local	Line brattices not extended to face. Poor installation	Igniting fuse with match	Electric blasting; proper installation of line brattice	Gas	1	0	4

TABLE 1.- Explosions in Colorado Coal Mines, 1883 to 1932 - Cont'd.

Case No.	Date	County	Type of opening	Tons per year	No. employed	No. in mine	Extent of explosion	Cause of presence of explosive atmosphere	Possible source of ignition	Possible means of prevention at time	Gas or dust explosion	No. killed	No. injured	No. escaping uninjured
111	6/19/1925	Huerfano	Slope	47,236	30	-	Local	Cutting machine truck left under curtain	Electric arc	Proper ventilation; water on cutter bar	Gas	3	0	Unknown
112	1/23/1926	Garfield	Drift	Wagon mine	2	2	Entire mine	No fan. Mine not inspected regularly	Open lights	Positive thorough ventilation; permissible lamps	Gas-dust	3	0	0
113	1/29/1926	Las Animas	Slope	30,556	35+	35	do.	Insufficient ventilation of workings. Failure to drive crosscut at face before abandoning section	do.	Proper ventilation; permissible lamps	do.	4	6	25
114	5/27/1927	do.	do.	456,437	175	84	Local	Mine was partly rock-dusted but not sufficiently to prevent propagation of flame in certain places. Dust raised by wrecked trip	Runaway trip on slope broke power cable. Arc ignited dust raised by trip	Sprinkling trips; buried armored cable	Dust	7	-	77
115	2/5/1930	do.	do.	None	-	-	-	Abandoned	Unknown	Sealing of abandoned mines	Gas	0	0	0
116	7/13/1931	Gunnison	Drift	127,035	183	157	Outside on tipple	Dust cloud at tipple	Loose connection on crusher motor	Better wiring	Dust	0	2	-
117	7/23/1931	Las Animas	do.	55,470	89	1	Local	Insufficient and improper ventilation of rooms; no line brattice	Blown-out shot or spit of fuse	Electric shooting; proper ventilation	Gas-dust	1	0	-
118	10/23/1931	do.	do.	Abandoned	-	4	do.	No ventilation. Abandoned mine	Open lantern carried by experienced miner exploring old mine	Sealing abandoned mines	Gas	3	1	0
119	12/20/1932	Huerfano	Slope	58,832	122	67	do.	Leaking of gas from sealed area	Electric arc from open-type switch on hoist	Escaping gas carried directly into return air course	do.	1	1	65

As shown by table 2 there were only 7 years during the period of 50 years (1883 - 1932) without record of an explosion or gas ignition in the coal mines of Colorado, and only 13 years without record of a fatality due to an explosion.

TABLE 2.- Number of Explosions and Men Killed and Injured by Years in Colorado Coal Mines

Year	No. of explosions	No. killed	No. injured	Year	No. of explosions	No. killed	No. injured
1883	1	1	3	1909	4	13	-
1884	2	59	2	1910	3	210	-
1885	1	1	4	1911	2	18	4
1886	0	0	0	1912	4	17	5
1887	0	0	0	1913	1	37	-
1888	8	8	25	1914	2	3	-
1889	1	-	1	1915	1	2	-
1890	2	1	5	1916	0	0	0
1891	2	2	1	1917	1	121	-
1892	2	3	4	1918	1	3	4
1893	5	24	6	1919	2	31	-
1894	1	-	6	1920	-	-	-
1895	4	4	3	1921	1	5	-
1896	4	49	3	1922	1	17	-
1897	4	12	4	1923	2	16	-
1898	2	-	2	1924	1	1	-
1899	5	0	7	1925	1	3	-
1900	9	0	15	1926	2	7	6
1901	11	10	23	1927	1	7	-
1902	7	22	8	1928	-	-	-
1903	1	1	-	1929	-	-	-
1904	1	19	-	1930	1	0	0
1905	0	0	0	1931	3	4	3
1906	4	35	2	1932	1	1	1
1907	3	26	-	Total	119	797	147
1908	4	4	-				

NATURE OF EXPLOSIONS IN COLORADO COAL MINES

Records of 119 explosions and gas ignitions in Colorado coal mines have been compiled; however, 91 of these occurred before 1911. Their nature with reference to gas or coal dust is shown in the following table:

TABLE 3.- Nature of explosions with reference to gas or coal dust

Nature of explosion	No. of explosions	No. killed	No. injured
Gas	81	114	113
Dust	21	186	25
Gas and dust	17	497	9
Total	119	797	147

Of the 81 gas explosions listed, 46 occurred without killing anyone, and 1 occurred without injuring or killing anyone. The above table shows that nearly as many persons were injured as were killed in the gas explosions.

Of the 21 dust explosions listed men were injured in only 3 and no one was killed. The number of men injured was approximately 13.5 percent of the number of men killed.

Of the 17 gas and dust explosions listed not one occurred without killing someone; the number injured was approximately 1.8 percent of the number killed.

These figures indicate the necessity of thorough rock-dusting and of sprinkling places and trips where possible to prevent participation of dust in explosions in bituminous and lignitic coal mines. A gas and dust explosion is likely to be more disastrous than either a gas or a dust explosion alone; in fact, nearly all widespread coal-mine explosions have involved both gas and dust.

TABLE 4.- Sources of ignition

Cause	No. of explosions	No. killed	No. injured
Known to be open lights	26	187	54
Records not clear, probably due to open lights	53	12	57
Fires in mines	2	80	4
Flame safety lamps	5	176	1
Explosives	20	162	21
Electricity	7	97	3
Spontaneous combustion	1	3	4
Matches	2	5	1
Stove on tipple	1	0	2
Unknown	2	75	0
Total	119	797	147

Open lights.- Records show that open lights caused at least 26 explosions in which 187 men were killed and 54 injured. Incomplete older records indicate that open lights caused 53 additional explosions which killed 12 men and injured 57. The need of safe illumination for coal miners was recognized as long ago as 1815, when Davy and several others developed flame safety lamps. Over 20 years ago portable electric cap lamps were introduced into the coal mines, and now more than 250,000 permissible-type portable electric cap lamps are used in United States coal mines. Later-type lamps give as much or more light than carbide lamps, and it is probable that the yearly cost of electric lamps is less than that of carbide lamps.

The Bureau of Mines recommends that "in all coal mines the portable lamps for illumination be permissible, portable, electric mine lamps."[4] The Bureau of Mines makes this recommendation from the standpoint of safety, not only on account of the gas-ignition hazard and the fire hazard of open-flame lamps but also because of the much greater dependability of up-to-date permissible electric cap lamps. In view of past experiences with the ignition of explosive gas by open-flame lamps and the demonstrated practicability of electric cap lamps, it is surprising that any coal-mine operators now allow open lights in their mines or that mine workers continue to use equipment known to be both unsafe and inefficient.

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[4] Bureau of Mines, Mine Safety Board Decision No. 1: Inf. Circ. 6732, Bureau of Mines, 1933, 43 pp.

Flame safety lamps.- Five explosions, killing 176 men, were probably due either directly or indirectly to improperly assembled or handled flame safety lamps. With a record of 176 of 797 deaths known to have occurred in Colorado coal mines the name "flame safety lamp" appears to be a misnomer, at least as applied to its experience in Colorado.

The Bureau of Mines has approved flame safety lamps for inspection purposes in gaseous mines, with the knowledge that they are safe to use in such mines if proper care is taken of them, but they are by no means "fool proof." One explosion was caused by a safety engineer taking his key-locked flame safety lamp apart underground and trying to relight it with a match; such an act is difficult to understand, but it explains in part why only magnetically-locked flame safety lamps should be used and why the lock should be kept in proper working condition and the magnet for opening the lamp should be available only outside the mine. In another explosion initiated by a flame safety lamp and causing the death of several people a fire boss was using a defective flame safety lamp which ignited some gas; this again shows that even in the hands of supposedly competent experts the lamp has its hazards.

Explosives.- The use of black blasting powder or dynamite or the improper use of permissible explosives caused 20 explosions resulting in the death of 162 men.

As early as 1898 there was on the market a so-called "Atlanta flameless powder" recommended by the Colorado State mine inspector for use in dusty and gassy mines.

In 1907 the first explosives now designated as "permissible" were used. Since that time explosives manufacturers have continually improved permissible explosives, and it is now possible to obtain permissible explosives that under intelligent usage will give virtually as effective blasting results as black powder. Explosives engineers have proved that the production of lump coal does not depend wholly upon the speed of detonation of an explosive and that strength and density are also important factors. The best method of determining the proper explosive to use in any coal is to consult the manufacturers, who have engineers well-qualified to recommend the grade of permissible explosives that should be used.

If permissible explosives are not used according to the methods prescribed by the Bureau of Mines and the manufacturers of explosives they may ignite an explosive mixture of gas or a coal-dust cloud. Even though the explosive is properly manufactured and approved by the Bureau of Mines it is not permissible if used in any of the following ways:

1. If stored under improper conditions until it undergoes a change in character.
2. If used frozen or partly frozen.
3. If used in excess of 1½ pounds per shot.
4. If the diameter of the cartridge is less than that designated in the column "smallest permissible diameter."
5. If fired with an electric detonator of less efficiency than that prescribed.
6. If fired with fuse.
7. If fired without stemming.
8. If fired with combustible stemming.
9. If fired in the presence of a dangerous percentage of firedamp.
10. If the shot is a depending shot, is bored into the solid, or has a burden so heavy that the shot obviously is likely to blow out.

Some coal mines in Colorado continue to use black powder in blasting, and some mines in the State use permissible explosives but detonate them by means of fuse; electric detonators cost slightly more than fuse and detonators, but their safety is so much greater that the minor difference in cost should not be considered in comparison with the numerous safety advantages of electrical blasting.

Electricity.- Ninety-seven men lost their lives, and 3 were injured in 7 explosions in Colorado caused by electricity. With the increasing use of electricity in general in the United States there has been an increased number of gas ignitions and coal-dust explosions, and even more than 7 explosions might have been expected in Colorado from this cause. The first explosion in this record due to electricity in Colorado occurred October 8, 1910, the last in December 1932. One explosion occurred at the tipple on the surface.

Marked improvement could be made in electrical installations in the coal mines of the State with regard to explosion and contact dangers. The haphazard manner in which electrical feed wires and electrical equipment are installed in many mines and tipples in the United States, as well as in Colorado, invites trouble from fires, is likely to lead to gas ignitions and explosions, and often offers utterly unnecessary man-contact hazards. In contrast, virtually all States have electrical building codes which, if applied to mines, would prohibit such installations as obtain in many if not most instances underground. These codes, moreover, apply only to buildings in which there ordinarily is no explosion hazard but only danger from fires and contacts.

Spontaneous combustion.- Numerous coal mines in Colorado are subject to spontaneous combustion. One fire from spontaneous combustion caused an explosion resulting in the death of 3 men and injury to 4 others. In the comparatively flat beds in northern Colorado, where spontaneous combustion of coal is frequent, the mining and ventilation methods developed have decreased the number of such fires and have usually made feasible their ready isolation and control. However, some steeply pitching coal beds in the State are subject to spontaneous combustion, and the control of fires in such beds is difficult and sometimes virtually impossible.

Fires in mines resulting in explosions.- While men were fighting the two mine fires listed as cases 91 and 97 explosions occurred which killed 80 men and injured 4. No gas had ever been found at the mine in case 91, nor was any found after the explosion. Some persons think the explosion was caused by the generation of carbon monoxide, others believe it was methane or other similar gas distilled from heated coal and coal dust. In this case exactly what set the door on fire is uncertain; open lights were used, and as the drivers usually ate their lunches by the door it is thought that a pile of wood chips, lunch papers, or the door itself caught fire from the flame of the open lights. It was while fighting this fire that the explosion occurred which killed 79 men, another instance indicating the hazards of open lights and of combustible doors, especially those on haulage roads in coal mines.

Matches.- Cases 69 and 110 are listed as due to matches. These two explosions caused the death of 5 men and injury of 1. In case 69 five men were working over an abandoned shaft which they knew was filled with explosive gas. It is believed that one of the men struck a match to light his pipe. In case 110 the shot firer lighted the fuses with a match.

Stove in the Tipple.- In case 37 a trip of cars broke away at the head of an incline and crashed into the tipple; the resulting dust cloud was ignited by an upset stove. Heating tipple houses with steam would remove such a source of ignition.

Unknown.- Cases 89 and 115 are listed as resulting from an unknown cause. Probably a blown-out shot of black blasting powder caused the explosion in case 89. The mine listed as case 115 had been abandoned for a number of years and stripped of all usable material but had never been sealed; the explosion probably was caused by some one outside the mine with an open flame. This mine was gassy and is the same one in which the disaster listed as case 108 occurred.

CAUSES OF GAS ACCUMULATIONS IN GAS AND GAS-AND-DUST EXPLOSIONS

Almost every gas accumulation is due to improper ventilation. Information is not available in every instance on the particular defects in ventilation at mines where the explosions listed occurred before 1910. Many lessons, however, can be learned by studying the defects given in table 5 that are known to have caused explosions.

TABLE 5.- Causes of gas accumulations in gas and gas-and-dust explosions

Cause	No. of explosions	No. killed	No. injured
1. Air short-circuited through doors or curtains	8	181	6
2. Fan stopped or was run intermittently	4	38	0
3. Line brattices poorly installed or no line brattices	5	64	4
4. Machine truck left under curtain, short-circuiting the air	1	3	0
5. Abandoned mine	2	3	1
6. Abandoned or old workings	3	6	9
7. No fan, natural ventilation	1	3	0
8. Crosscut left open to remove rock for construction of overcast	1	2	0
9. Pocket of gas accumulating in high point in roof or workings driven to the rise	2	5	4
10. Failure to drive crosscuts at proper intervals	1	4	6
11. Gas distilled by mine fire	2	80	4
12. Gas leaking from sealed area	2	3	10
13. Unable to detect less than 2 percent of methane on flame safety lamp	1	49	0
14. Gas feeder ignited by open lights	1	1	4
15. Improper ventilation	4	4	12
16. Cave caused accumulation of gas	1	3	2
17. Brushing out gas	1	0	1
18. Sudden outburst of gas	2	33	2
19. Uncertain	56	129	57
Total	98	611	122

Air short-circuited through door.- It is almost impossible to operate a mine without some doors, but this is no reason why doors should not be used in pairs to form an airlock or should not be supplemented by curtains. Doors should be self-closing and should not be equipped with devices or attachments to hold them open. They should be fireproofed and so constructed that there is a minimum of air leakage.

Fans.- In gassy mines, particularly those of considerable size, fans driven by electric motors should be so equipped with automatic starters that they will automatically start again if the power is interrupted; they should also be equipped with a device to shut off electric power in the mine in the event of fan stoppage. A mine fan should be run 24 hours every day; if a fan must be stopped for repairs all men should be removed from the mine, and the mine should be thoroughly examined by competent men before the electric current is turned on underground and before the other men are allowed to enter it.

Line brattice.- Judging from the haphazard methods by which line brattices and curtains are installed in some mines it is apparent that many mine officials and men are loath to take such installations seriously. When properly installed and with enough air available line brattices are the best means of ventilating working faces when advancing between crosscuts or breakthroughs. However, there is leakage of air even with the best-installed curtains and brattices, and long line brattices are likely to be inefficient or even dangerous.

Equipment under curtains.- It will be noted that in one case an accumulation of gas with a resultant explosion is attributed to short-circuiting of the air by equipment, such as mining machines, cars, etc., left under curtains. Mine officials and workers should be alert to the avoidance of such practices, as they are unnecessary and obviously dangerous in the extreme.

Abandoned mines.- Two explosions, cases 115 and 118, kiling 3 men and injuring 1, occurred in abandoned mines. The explosion in case 118 occurred while miners working in a gassy mine were exploring an abandoned mine in the same coal field in which their own mine was situated to determine whether they could mine out the old pillars. These men carried ordinary farm-type lanterns for light and should have known the extreme hazard of open lights in unventilated underground workings known or even likely to give off explosive gas.

Only a few explosions in abandoned mine are on record, but each year a number of persons are killed by ignition of explosive gas or suffocated by gases while exploring old mines that have not been sealed. When a mine is abandoned it should be effectively sealed, as required by law in many States.

Abandoned or worked-out areas.- Three explosions, resulting in the death of 6 men and the injury of 9 others, were caused by miners who entered an abandoned section of the mine while wearing open lights. In case 4 men stepped over a plainly marked "fire (or danger) board" to enter the gas filled region.

In the interest of safety the Bureau of Mines recommends that in coal mines all entries, rooms, panels, or sections that cannot be kept well ventilated throughout or cannot be inspected regularly and thoroughly, or that are not being used for coursing the air, travel, haulage, or the extraction of coal be sealed by strong fireproof stoppings.[5]

Natural ventilation.- To rely on natural ventilation for circulation of air through a coal mine is little short of criminal negligence, yet small mines often attempt to get along without fans. Efficient fans are now on the market at low cost, and if a mine operator cannot afford such a fan he should not be permitted to open or operate a coal mine.

Crosscut left open to remove rock.- Why any supervising official would permit men to work or electric power to be on the wires inby a point where the ventilating current had been short-circuited cannot be satisfactorily explained, yet this is done, at least in some instances with fatal consequences.

Gas accumulation in high points and in working to the rise.- On account of breaks and irregularities in the overlying strata high points often occur in the roofs of entries, aircourses, and rooms, as well as in pillar workings. Such places should be examined regularly for methane accumulations; if methane accumulates at such points they can be ventilated by brattice installed at the roof or by a pipe running from the high pocket directly into the return, thus passing the gas into the return airway, and in some instances it is discharged to the surface through boreholes suitably placed.

Where working places are driven to the rise in gassy mines officials should insist that the line brattices be kept close to the face and properly installed, also that crosscuts be driven at proper intervals and that there be enough air at the working faces to keep them clear of dangerous percentages of gas.

Crosscuts at regular intervals.- The Colorado mining law provides that crosscuts shall be driven as often as inspectors may order, but under no circumstances shall they be more than 60 feet in advance of the air current. Explosions have occurred because there was delay in driving such crosscuts, and this is particularly likely to occur in rise workings (crosscuts, entries, or rooms).

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[5] See footnote 3.

Gas from sealed areas.- Where possible, sealed regions should be located on the return air so that any gas leakage from such areas will not pass into live workings. Regular examinations should be made of the return air outby such seals to insure that an explosive mixture of inflammable gas is not present in the return, or in openings between the sealed region and the return.

Gas distilled from mine fires.- Mine fires are very likely to distill gases from the coal; these gases may be explosive, another reason why mines should take all feasible precautions against occurrence of mine fires and why mines should be equipped with fire-fighting apparatus underground. In both cases cited in this paper the fire could have been extinguished soon after discovery had such equipment been available.

Unable to detect less than 2 percent of methane with old safety lamps.- The State inspection department blamed some of the explosions from 1883 to 1898 on the fact that an instrument that would indicate the true percentage of gas was not available. The State mine inspector's biennial report for 1895-96 very definitely calls attention to the fact that few if any miners could detect on their safety lamps less than 2 percent and some not less than 4 percent of inflammable gas and that such percentages were too close to the explosive range for safety.

Permissible methane detectors that will record accurately less than 0.25 percent of methane are now on the market. Such detectors will tell mine officials much about the gassy conditions of their mines that they do not now know, and they will be of assistance in placing the ventilating currents where most needed; any mine in which explosive gas occurs should be provided with this up-to-date equipment and use it daily.

Feeders at working faces.- Where gas feeders occur extreme care should be taken to insure ventilation of the place so as to dilute the gas-air mixture below 0.50 percent. Open lights and black blasting powder certainly should not be used in mines wherein gas feeders occur or are likely to occur.

Improper ventilation.- Under this heading have been placed cases in which the air courses were known to be too small or had been allowed to fill up, or little or no effort had been made to send air into the working faces; conditions of these types are conducive to the accumulation of explosive gas. Some operators still do not realize the importance of clean air-courses of proper size or would rather gamble with an explosion than spend the money necessary to put aircourses in proper condition.

Brushing out gas.- The practice of brushing out gas has been condemned in Colorado ever since the first coal-mine inspector was appointed. In his first report he recommended for moving gas the use of brattice cloth, to be erected while all lights were out of the section.

Caves causing accumulations of gas.- Possible liberation of explosive gas when caving occurs is ordinarily anticipated by mine officials, and proper examinations are generally made of such caves. However, even small caves may liberate gas, and all caved areas near active workings should be examined as far as they are accessible during the regular fireboss inspection.

Sudden outburst of gas.- This hazard (the sudden outburst of explosive gas) is present in some mines and can be handled with relative safety by proper ventilation and by the use of permissible equipment and permissible devices exclusively. The alertness and knowledge of the mine officials are great factors in avoiding all hazards in coal mines and are of especial value in the prevention of explosions and fires, and probably in no other phase of coal mining is the alertness and vigilance of officials more essential than in the avoidance of serious troubles in mines wherein outbursts of gas or dust, or both, may occur.

CAUSES OF DUST CLOUDS IN DUST EXPLOSIONS AND IN GAS-AND-DUST EXPLOSIONS

Rock-dusting prevents clouds of coal dust from being explosive, and thorough sprinkling of coal piles and loaded cars decreases the likelihood that a coal-dust cloud will be raised. Unless coal dust is actually wet (in general, this is difficult to accomplish) it may be raised into a cloud and ignited, causing an explosion, or may feed (or propagate) an explosion started elsewhere. The 38 explosions listed in table 6 illustrate the danger of coal dust when raised into a dense cloud and brought into contact with flame or an electric arc.

TABLE 6.- Causes of dust clouds in dust explosions and in gas-and-dust explosions

Cause	No. of explosions	No. killed	No. injured
Dust cloud raised by cave	1	37	0
Wreck of haulage trip (trip not sprinkled)	2	63	0
Dust cloud raised by blasting	17	88	21
Dust cloud at tipple operations	2	0	4
Dust cloud raised by gas explosion	16	495	9
Total	38	683	34

Dust clouds caused by caves.- Caves, whether in active or in abandoned workings, besides liberating gas or causing gas accumulations have an additional hazard of raising a dense cloud of dust. Whether or not such clouds are explosive depends on their combustible content and density. Thorough rock-dusting of all accessible parts of mines, including abandoned open areas, will make such clouds noninflammable, and exclusion or restriction of open flames or flame-making equipment or devices will tend to prevent ignition of gas bodies or of dust clouds, even if they should occur.

Dust clouds caused by haulage.- Proper maintenance of haulage roads, thorough rock-dusting of haulage entries, and sprinkling of road beds and trips of cars would have prevented the explosions listed as cases 90 and 114.

Dust clouds from blown-out shots.- Improper location of drill holes, shooting off the solid, firing of dependent shots, use of too little or no stemming, and loading holes too heavily cause blown-out shots. These can be eliminated by proper supervision, assisted by safety education of miners and shot firers. Also, if the shots are loaded and fired when the working shift is out of the mine the likelihood of wholesale fatalities from explosions caused by blown-out shots or from other causes in connection with the use or abuse of explosives in coal mines will be eliminated.

Dust clouds caused at tipple operations.- Many coal men believe that the dust cloud raised by tipple operations is not dense enough to explode. The explosions listed as cases 37 and 116 show the fallacy of this opinion and the necessity of properly installing and maintaining electrical equipment and keeping tipples clean.

Dust clouds raised by gas ignition.- In Colorado as well as in nearly every State in which widespread explosions have occurred the usual causes have been an initial or local gas ignition, which usually affected only a relatively small area of underground workings, and an extension of the explosion through other parts of the mine or the entire mine by stirring the coal dust from the mine surfaces (floor, roof, ribs, and timbers) with accompanying ignition of the dust. Unless the immediate region in which the original gas ignition occurred was so wet that coal dust could not be stirred with the air or unless the dust was so thoroughly mixed with other incombustible (rock) dust as to be incapable of ignition and ex-

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plosion the concussion from the original ignition of explosive gas was usually enough to cause the available dust from surrounding surfaces to be thrown into the air to feed the flame. This process usually was a continuing one if the mine workings were dry and rock-dusting had not been kept in effect efficiently.

The real solution of this type of explosion is the prevention of accumulations of explosive gas through proper ventilation; but this is not at all times feasible, and the problem is the more difficult since a very small quantity of an explosive mixture of gas and air (sometimes as little as 150 or 200 cubic feet) upon ignition can precipitate a widespread explosion if adjacent conditions as to dust, etc., are favorable. Hence, in addition to adequate ventilation and the elimination of open lights or other igniting agencies at or near faces or other places where explosive gas (and dust) may be expected it is extremely desirable that the surfaces of the immediate face region back about 40 or 50 feet be kept wet and that the surfaces of the remainder of the face region and the entire accessible open parts of the mine be kept well rock-dusted.

EXPLOSIBILITY OF COLORADO COAL DUST

Tests by the United States Bureau of Mines show that semianthracite, bituminous, and subbituminous coal dust is explosive under certain conditions. Anthracite dust is not thought to be explosive under ordinary conditions.

Experiments by the Bureau of Mines have proved that the ratio of volatile combustible to volatile combustible plus fixed carbon in the coal, expressed as V.M./V.M. + F.C., is an index of the explosibility of coal dust; the higher the volatile combustible matter the more explosive the dust, other factors being equal.

The following table shows this ratio, as calculated from available analyses, for coal from various counties in the State. (The ratio varies slightly for different mines.)

TABLE 7.- Ratio of volatile combustible to total combustible, by counties

County		Ratio, VM/VM + FC
Adams..........		0.402 to 0.475
Boulder......		.396 to .482
Delta..........		.428
Elbert........		.489
El Paso......		.472 to .482
Fremont......		.436
Garfield....		.409
Gunnison....	Bituminous	.254 to .459
	Anthracite	.034 to .078
Huerfano....		.431 to .446
Jackson......		.433 to .515
Jefferson..		.469
La Plata....		.406 to .458
Las Animas		.380 to .445
Mesa............		.419 to .431
Moffat........		.463 to .486
Montezuma..		.264 to .510
Ouray..........		.479
Pitkin........		.234 to .374
Park............		.414
Rio Blanco		.386 to .501
Routt..........		.388 to .415
Weld............		.381 to .542

Any coal dust that has a ratio of volatile to total combustible exceeding 0.15 is explosive. The presence of any quantity of inflammable gas in the mine air increases the explosibility of the dust, therefore an additional quantity of rock-dust must be added to neutralize the effect of the gas present.

For purposes of comparison, dust from the Pittsburgh seam in Pennsylvania, West Virginia, and Ohio has an average V.M./V.M.+F.C. of about 0.40. From table 7 it will be noted that dust from most of the bituminous coals of Colorado is at least as explosive as that from the coal of the Pittsburgh bed in Pennsylvania, and scores of tests of the Bureau of Mines at the Experimental mine, Bruceton, Pa., indicate that the dust of the Pittsburgh bed is among the most explosive dusts of the coal mines of the United States.

No coal-dust explosions of record have occurred in some counties in Colorado, particularly in the northern lignitic or subbituminous field. Probably the high moisture content of the coals in the northern field, supplemented considerably by good luck, has some bearing on this. The Bureau of Mines in its tests has initiated explosions in the absence of gas with coals having fully as high a moisture content as that in northern Colorado, and the past immunity from explosions is no guarantee that dust explosions cannot occur in mines producing these coals.

CONCLUSIONS

To have an explosion in a mine or on a tipple there must be an explosive mixture of methane and air, or a dense coal-dust cloud, or both, and enough heat must be present in the form of an open flame or an electric arc to ignite the mixture. Black blasting powder or dynamite when detonated may produce the necessary dust cloud and the flame may ignite the dust. When an explosion is initiated the advance wave may raise the dust cloud in front of the explosion flame and thus carry the explosion throughout the mine. Accumulations of explosive gas can be prevented by proper and thorough ventilation. Accumulations of explosive coal dust can be prevented by the application of enough rock-dust and by removing accumulations of coal-dust. Sprinkling of wall faces, coal piles, and trips of cars in a large measure prevents the air current from carrying dust throughout the mine. The possible sources of ignition can be decreased by the use of permissible equipment and permissible explosives, provided that the equipment and the explosives are maintained and used in a proper and safe manner.

Spontaneous combustion is a possible source of flame, and suitable mining methods can prevent spontaneous fires or can isolate and smother them if they occur; good ventilation will largely eliminate the danger of accumulation and ignition of gas from such a source.

The explosions listed in this paper did not just happen; they were caused by circumstances over which those engaged in coal mining had control. In recent years few lives have been lost in Colorado by coal-mine explosions compared with earlier years, undoubtedly due to better understanding by operators of coal-dust and gas hazards and to increased vigilance by the State mine-inspection department, as well as the operators and mine workers themselves. Nevertheless, the disastrous coal-mine explosion history of Colorado in the past and the fact that several minor explosions have occurred in recent years emphasize the need for continued vigilance on the part of all and the complete adoption and continued enforcement of explosion-prevention measures now well-known and readily available.